NUSEA—Measurement of the Asymmetry in the Light-Antiquark Nucleonic Sea

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Recent measurements of deep inelastic muon scattering by the New Muon Collaboration (NMC)[1] have suggested that the up sea antiquark ($\overline{u}_p$) and down sea antiquark ($\overline{d}_p$) distributions of the proton are not equal. The Gottfried sum rule,[2]

$$\begin{aligned} S_G &= \int_0^1 (F_2^p(x) - F_2^n(x))dx/x \\ &= \frac{1}{3} + \frac{2}{3}\int_0^1 (\overline{u}_p(x) - \overline{d}_p(x))dx, \end{aligned}$$

says that the integral over the nucleon momentum fraction (x) of the difference of the structure functions for the proton (F_2^p) and the neutron (F_2^n) divided by x should be equal to one-third plus a term that is zero if the $\overline{u}_p$ and $\overline{d}_p$ distributions are equal. The NMC result for the Gottfried sum rule is $S_G = 0.235 \pm 0.026$. This result implies that $\overline{u}_p < \overline{d}_p$ in the proton.

One possible cause for an enhancement of $\overline{d}_p$ over $\overline{u}_p$ is Pauli blocking.[3] Here the idea is that because the proton is composed of two up quarks and a down quark (uud), it is less likely that a $u\overline{u}$ pair can be formed since the u would be blocked by the two up quarks in the proton more strongly than a d from a $d\overline{d}$ would be blocked by the single down quark in the proton. Another possible cause is from the pion-cloud model[4] of the proton. In this model the proton can produce pions in the cloud through mechanisms such as the following:

$$\begin{aligned} &p \to p\pi^0 \Rightarrow p + \frac{1}{\sqrt{2}}(u\overline{u} + d\overline{d}) \\ &p \to n\pi^+ \Rightarrow n + (u\overline{d}). \end{aligned}$$

Together, these mechanisms give more down antiquarks than up antiquarks.

A direct measurement of $\overline{u}_p$ and $\overline{d}_p$ can be made using the Drell-Yan (DY) process (Fig. II-45), in which a quark from an incident proton annihilates with a sea antiquark in a target nucleus and forms a virtual photon that then decays into a $\mu^+\mu^-$ pair. If this measurement is done on hydrogen and deuterium targets, then the following is true:

$$\left.\frac{\sigma_{p+d}(x)}{2\sigma_{p+p}(x)}\right|_{x_F>0} \cong \frac{1}{2}\left(1 + \frac{\overline{d}_p(x)}{\overline{u}_p(x)}\right),$$

where $\sigma_{p+p}(x)$ is the DY cross section for protons incident on hydrogen, and $\sigma_{p+d}(x)$ is the DY cross section for protons incident on deuterium. Using this process, the NA51 Collaboration[5] at the European Center for Nuclear Research obtained the result $\overline{u}/\overline{d} = 0.51 \pm 0.04 \pm 0.05$ at $x = 0.18$. The NUSEA experiment E866 at Fermilab, which we report on here, has measured the deuterium to hydrogen ratio in the DY process over values of x ranging from 0 to 0.3. This range is much wider than that of the NA51 experiment, and

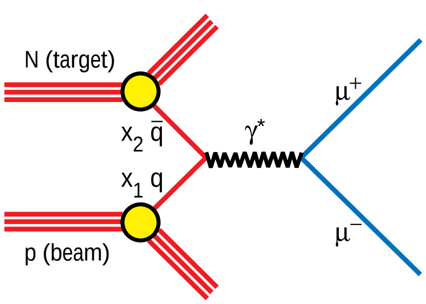

Fig. II-45. Diagram of the Drell-Yan process.

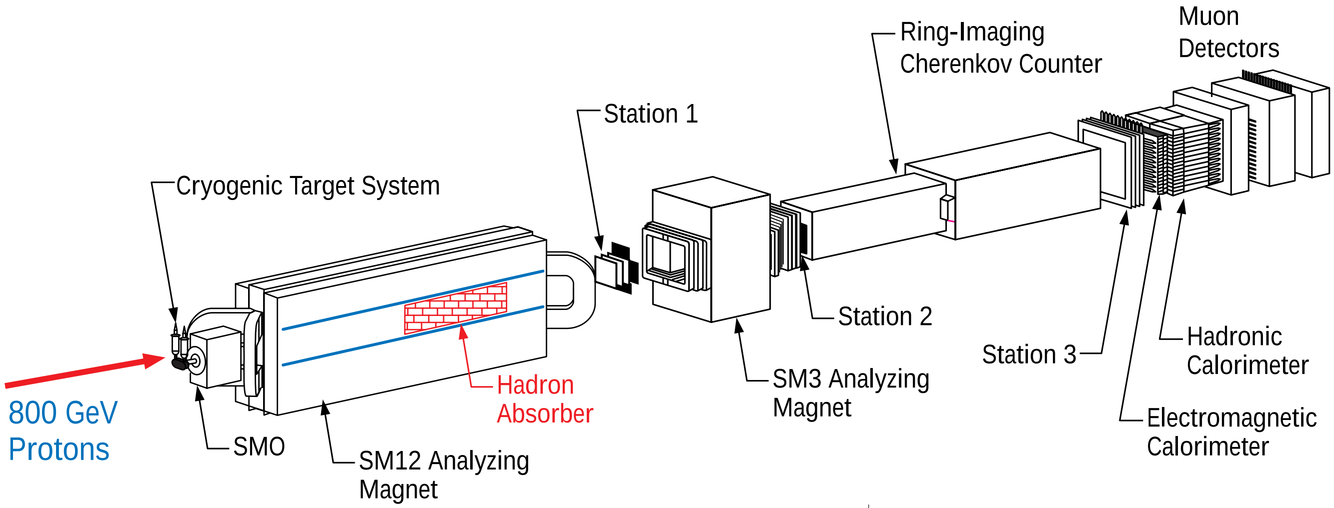

Fig. II-46 Schematic view of the NUSEA pair spectrometer.

the NUSEA experiment has over 350,000 events recorded, compared with NA51's 6,000 events. Los Alamos personnel are leaders in the NUSEA experiment and in two previous experiments, E772 and E789; all three experiments used the same spectrometer. The earlier experiments studied nuclear effects on dimuon production and the production of *D* and *B* mesons. Pat McGaughey, from Los Alamos, is the spokesperson for the NUSEA Collaboration.

The NUSEA pair spectrometer (Fig. II-46), which is on one of the 800 GeV/*c* proton beam lines at Fermilab, detects $\mu^+\mu^-$ pairs for very high incident-proton intensities ($\approx 10^{11}$ protons/s). Two 20-in.-long cryogenic targets, one filled with liquid hydrogen and the other with liquid deuterium, and an empty cryogenic vessel are located just upstream of the first magnet. On alternate 20-second beam spills, the target intercepting the beam is changed from deuterium to hydrogen to empty. The portion of the beam that does not interact with the targets is stopped in a 168-in.-long copper beam dump. Opposite-sign muon pairs are bent vertically above and below the beam dump by the first two magnets (SM0 and SM12) and are tracked through a series of scintillator hodoscopes and drift chambers before and after the last bending magnet (SM3). Using the hits in the drift chambers, we measure the bend angle in SM3 and, from this angle, determine the momentum of each muon. Then the muon tracks are traced backwards through the known magnetic field of SM12 and SM0, and the muons' momenta and direction at the target are reconstructed. Thick absorber walls both in SM12 and in front of a set of hodoscopes and proportional tube detectors assure that all of the tracked particles are muons because hadrons or electrons would not penetrate the absorbers. Finally, the pair mass is reconstructed from the tracks at the target.

A 6-month-long measurement of $\bar{u}/\bar{d}$ has just been completed, and analysis of the data is well under way. We present our preliminary results here. Data were taken at three magnetic-field settings that emphasized high, intermediate, and low masses. Figure II-47 shows the combined mass spectra for the three mass settings as well as that for the high-mass setting alone. In addition to the continuum DY

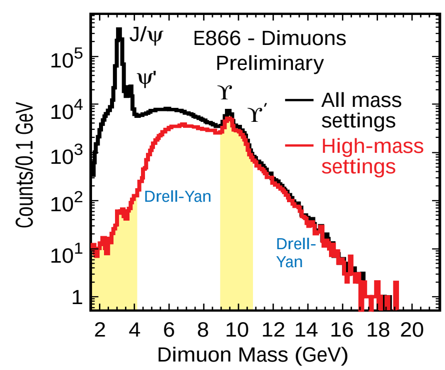

Fig. II-47. Dimuon mass spectra obtained in the NUSEA experiment. The black curve shows the composite spectra for the three mass settings, while the red curve shows the spectrum for the high-mass setting alone. Only the unshaded regions for the high-mass setting are used in the preliminary analysis presented here. The shaded regions were not used so that only DY would be included and all contributions from the resonance mass peaks excluded.

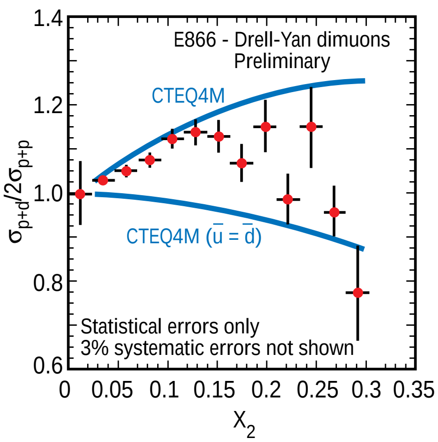

Fig. II-48. Preliminary results from the NUSEA experiment for the ratio of the deuterium cross section divided by two times the hydrogen cross section ($\sigma_{p+d}/2\sigma_{p+p}$) plotted versus the target momentum fraction (x_2) of the sea antiquark.

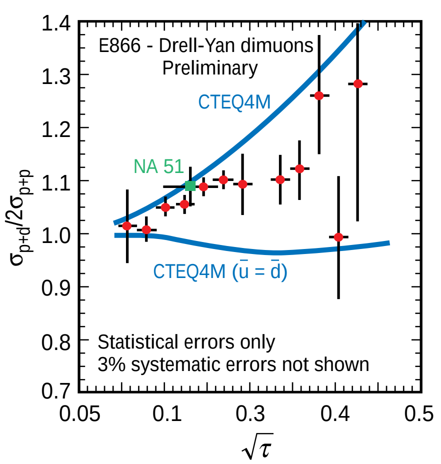

Fig. II-49. The same ratio seen in Fig. 4 plotted versus $\sqrt{\tau}$, where $\tau = x_1x_2$. The single data point from the NA51 experiment is shown along with the NUSEA data.

muon pairs, one also sees peaks corresponding to production and decay of the J/Ψ, Ψ', and Υ, and Υ' resonances. For the $\bar{u}/\bar{d}$ analysis that follows, we excluded the mass regions corresponding to these resonances. Preliminary results for the ratio of deuterium to hydrogen versus x, obtained from an analysis of most of the data for our high-mass setting, are shown in Fig. II-48. Results are not yet available for the other mass settings because of the need to correct for rate-dependence effects that are not present in the high-mass data. Also shown are theoretical calculations with phenomenological CTEQ4M[6,7] structure functions and a calculation based on CTEQ4M but with $\bar{u} = \bar{d}$. The former fixes its $\bar{u}/\bar{d}$ asymmetry from the NMC and NA51 data. In Fig. II-49 we plot the ratio versus $\sqrt{\tau}$, where $\tau = x_1x_2$, and x_1 and x_2 are the beam and target momentum fractions, respectively. Here the NA51 data point is seen to be consistent with our data.

As the analysis of our NUSEA data progresses and data from the other two magnetic-field settings are incorporated into our results, we will have a direct and accurate measurement of the $\bar{u}/\bar{d}$ asymmetry over a wide range of x. At the present our preliminary analysis confirms that $\bar{d}$ is enhanced over $\bar{u}$ when x is in the range of 0–0.2. Below about $x = 0.2$ our results agree well with the CTEQ4M theoretical result, but at higher x they fall substantially below it.

In addition to the $\bar{u}/\bar{d}$ asymmetry measurement, NUSEA has been approved for an extension during which we will address a number of issues, including many that relate to our future studies at the Relativistic Heavy-Ion Collider. We will measure the polarization of DY pairs and of J/Ψ resonances to try to better understand their production mechanisms, notably whether the J/Ψ resonances are initially produced in a color-octet state.[8] We will also measure the nuclear dependence of J/Ψ production near zero and at very large x_F (where $x_F = x_1 - x_2$) in order to better determine the most important nuclear effects in p-A reactions. Finally, we will study DY pairs at masses below the J/Ψ resonances and try to understand the different contributions to the continuum at these low masses.

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